Argonne NATIONAL LABORATORY

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In cooperation with the
U.S. Department of Transportation
Northern Illinois University
and the
University of Illinois

U.S. Department of Energy

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A U.S. Department of Energy laboratory managed by UChicago Argonne, LLC

Transportation Research and Analysis Computing Center

TRACC

David P. Weber, Ph.D.
Research Program Director
and TRACC Director
Energy Systems Division
Argonne National Laboratory
dpweber@anl.gov
http://www.tracc.anl.gov

In cooperation with the U.S. Department of Transportation,
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Argonne National Laboratory

Situated on 1,500 beautiful, wooded acres and surrounded by the Waterfall Glen Forest Preserve, Argonne National Laboratory is one of the nation's leading federally funded research and development centers.

- Argonne National Laboratory is one of the U.S. Department of Energy's oldest and largest national laboratories for science and engineering research.
- Since 1990, Argonne has worked with more than 600 companies and numerous federal agencies and other organizations.
- Argonne's mission is to apply a unique mix of world-class science, engineering and user facilities to deliver innovative research and technologies and actively seek opportunities to work with industry to transfer our technologies to the marketplace through licensing, joint research and many other collaborative relationships.
- Research at Argonne centers around the principal areas of Energy, Biological and Environmental Systems, and National Security
- Argonne is managed by UChicago Argonne, LLC, for the U.S. Department of Energy's Office of Science and is located in southwest DuPage County, Ill., 25 miles (40 km) southwest of Chicago.

TRACC – A National User Facility to Meet USDOT Advanced Computation Needs

- USDOT and USDOE transportation research programs, private industry, and state and regional transportation agencies are moving to simulation-based design and analysis for improvements in efficiency, economics, and safety
- Higher fidelity analysis in areas such as crashworthiness, aerodynamics, combustion, thermal management, weather modeling, and traffic simulation require access to state-of-the-art computational and visualization facilities
- Argonne expertise in high-performance computing and transportation system analysis provides the basis for a national HPC user facility and a focal point for computational research for transportation applications

TRACC – High-Performance Computing for Transportation Research and Applied Technology

Thermal Management

Crashworthiness

Bridge Hydraulics

Occupant Safety Assessment and Crash Biomechanics

Bridge Structural Analysis

Aerodynamics

Intelligent Transportation System

Road Weather Research

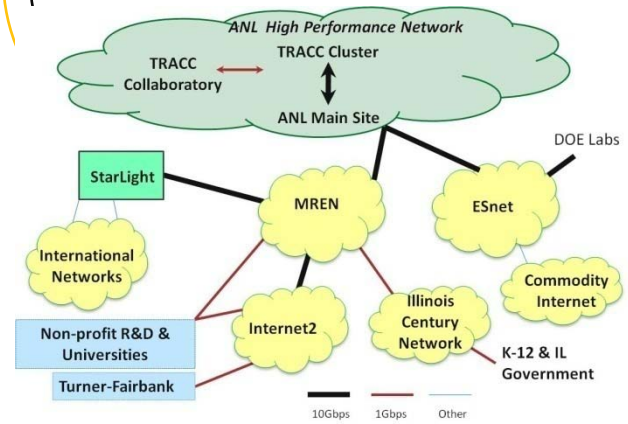
Traffic Modeling

Transportation Data Archive

TRACC Is a National USDOT Supercomputing Facility

TRACC High Performance Compute Cluster

- 512 cores /128 compute nodes
- 180TB Global Parallel File System Disk Storage
- 160TB Archive/Backup Tape Storage



High-bandwidth connectivity is provided via the Argonne high-performance network to world-wide research and education networks (Internet2 and ESnet)

TRACC Collaboratory - Visualization, Access Grid, and Digital Conferencing

Partner Organizations Add Expertise & Infrastructure

- Northern Illinois University (NIU)
  - Computational Fluid Dynamics for bridge hydraulics
  - Computational Structural Mechanics for bridge vibration analysis
  - Traffic simulation & evacuation planning
- University of Illinois (UIUC)
  - Visualization for traffic analysis
  - Loaned equipment & infrastructure for advanced visualization

- DuPage Airport Authority
  - Offices & Collaboratory
- DuPage National Technology Park
  - TRACC Cluster Operations

Current USDOT Application Focus Areas

- **Traffic Modeling and Simulation and Emergency Transportation Planning**
  - Chicago Metropolitan Area model using multi-modal micro-simulation techniques
  - Collaboration with the Chicago Metropolitan Agency for Planning, IDOT, FHWA and Northern Illinois University

- **Multidimensional Data Visualization**
  - Visualization of transportation system modeling from USDOT TRANSIMS modeling system with UIUC National Center for Supercomputing Applications

- **Computational Fluid Dynamics for Infrastructure Analysis**
  - Bridge hydraulics, including flooding and scour, using computational fluid dynamics (CFD)

- **Computational Structural Mechanics for Transportation Applications**
  - Bridge dynamics analysis, including bridge integrity under flooding and traffic or air-flow induced vibration

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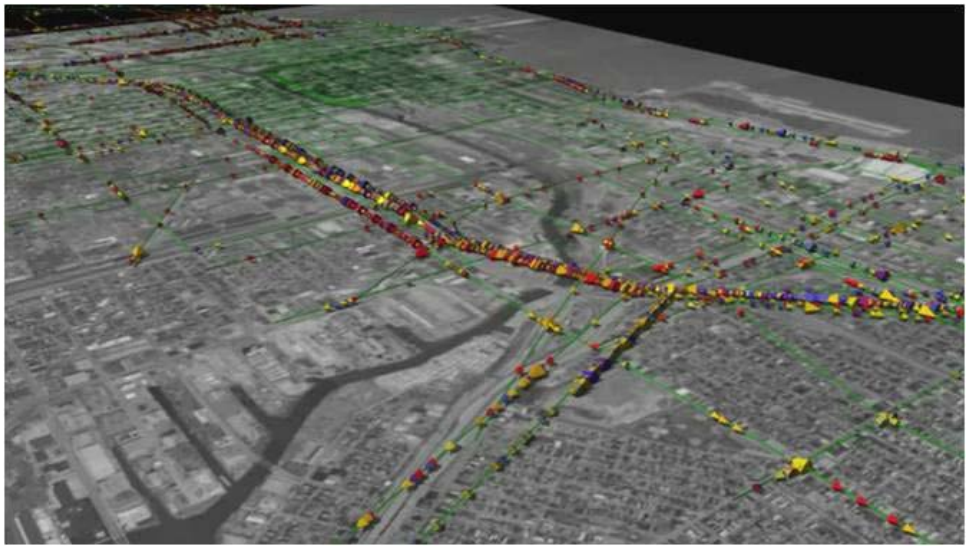
Traffic Modeling and Simulation and Emergency Transportation Planning

In cooperation with the U.S. Department of Transportation,
Northern Illinois University and the University of Illinois

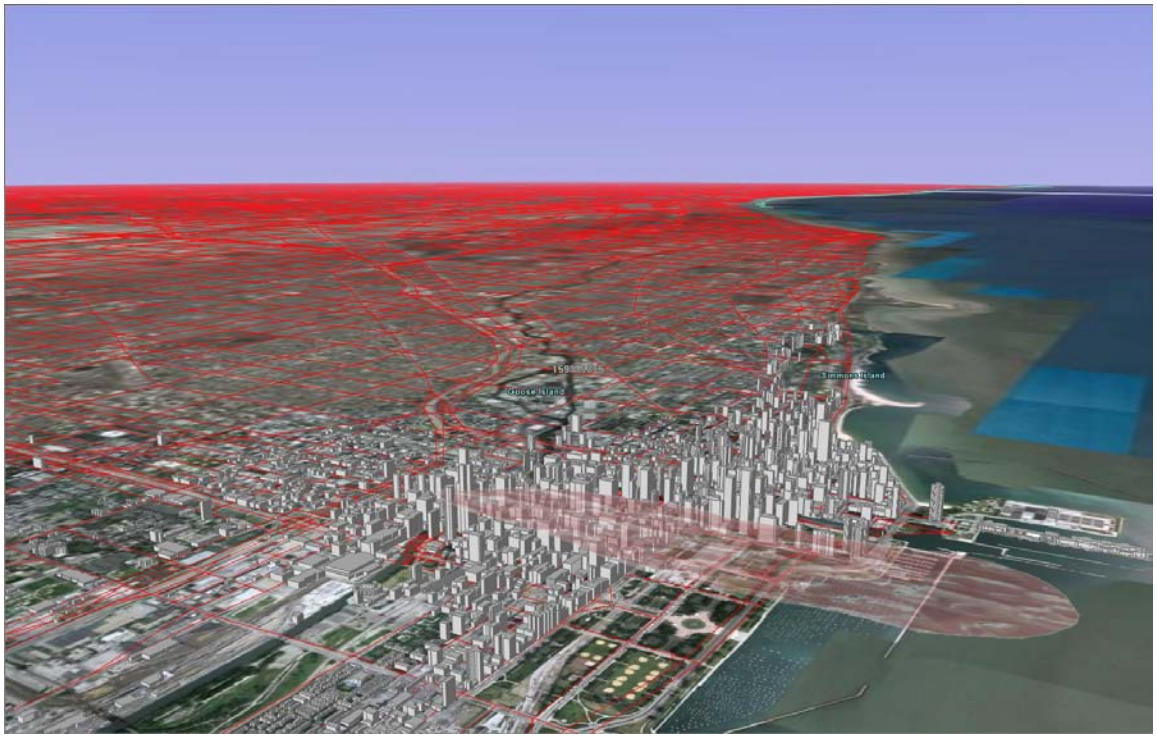
TRANSIMS Application

- Development of a detailed Chicago Metropolitan Area (CMA) model for TRANSIMS
  - TRANSIMS employs a new paradigm in traffic planning by tracking individuals during their daily travel
  - Extensive routing and microsimulation using cellular automata provides a high-fidelity simulation
- Detailed road network has been provided by CMAP (Chicago Metropolitan Agency for Planning)
  - This includes detailed trip data by purpose and diurnal distribution, as well as complete transit information



The ITTF Project

Development of a model for the simulation of an emergency evacuation scenario in the Chicago Business District

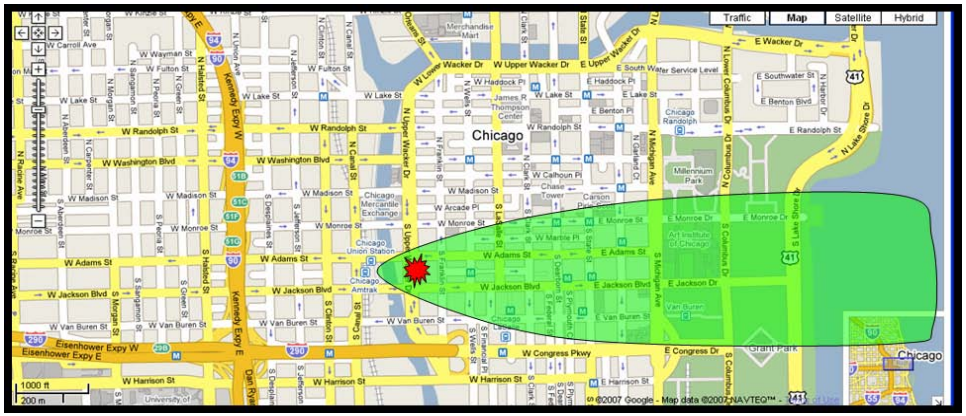


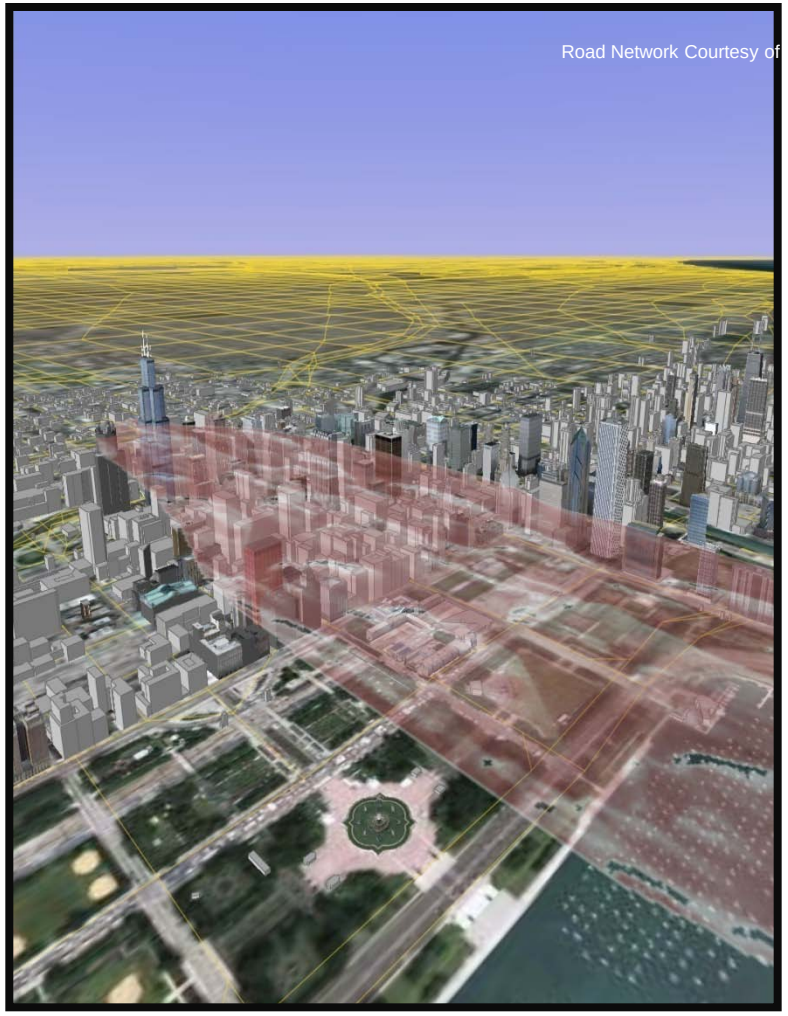
Sponsored by state and city agencies:

ITTF: Illinois Terrorism Task Force, IDOT: Illinois Department of Transportation, IEMA: Illinois Emergency Management Agency, IEPA: Illinois Environmental Protection Agency, USDOT/FHWA: U.S. Department of Transportation Federal Highway Administration

Emergency Evacuations of Chicago Business District

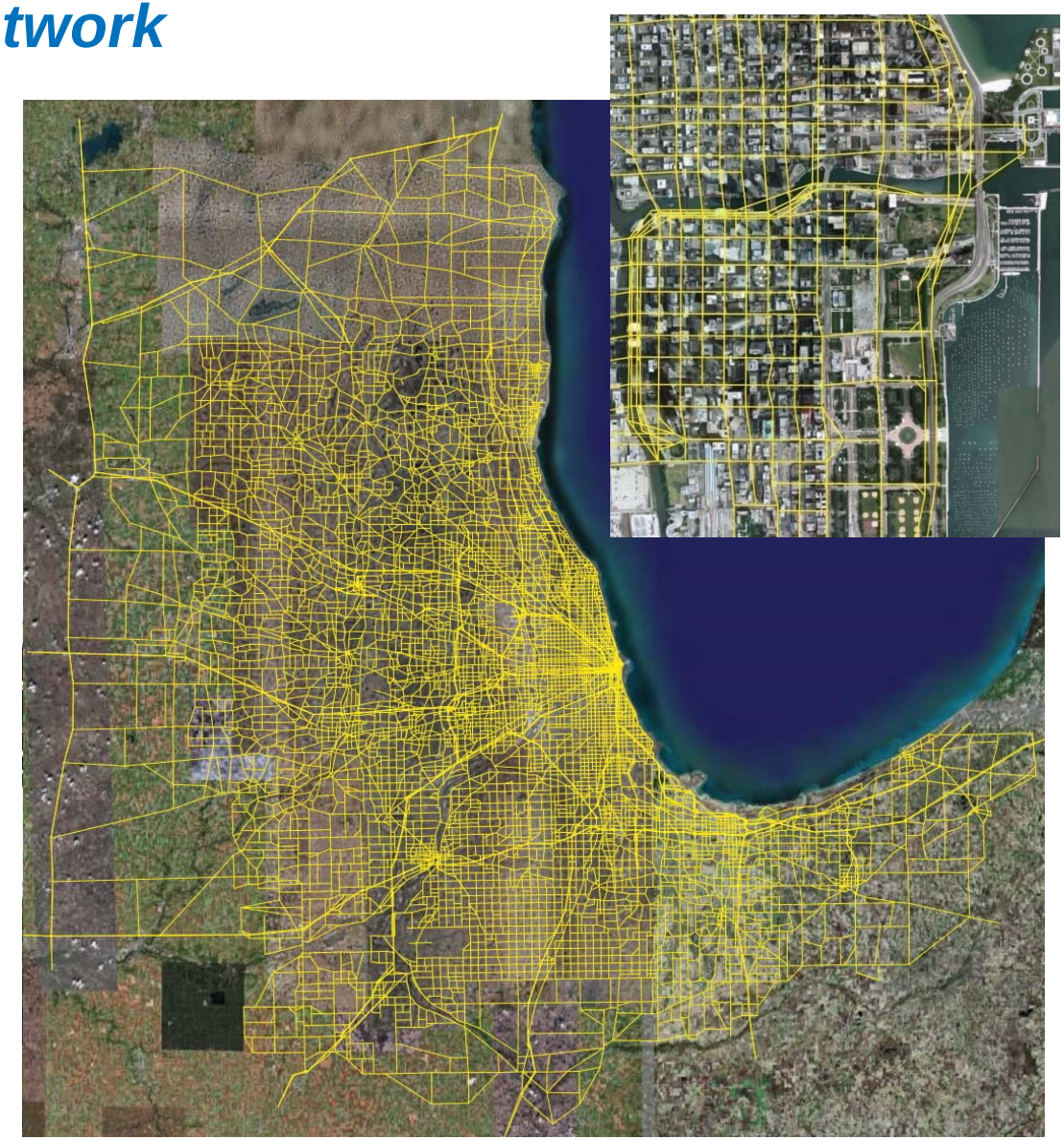
- This project has been implemented to model the effects of a no-notice event on the multi-modal regional transportation system in the Chicago metropolitan area
- The chosen scenario postulates a radioactive release following an explosion at the base of the Sears Tower
- This project deals with the dynamic effect on the transportation system





The Regional Road Network

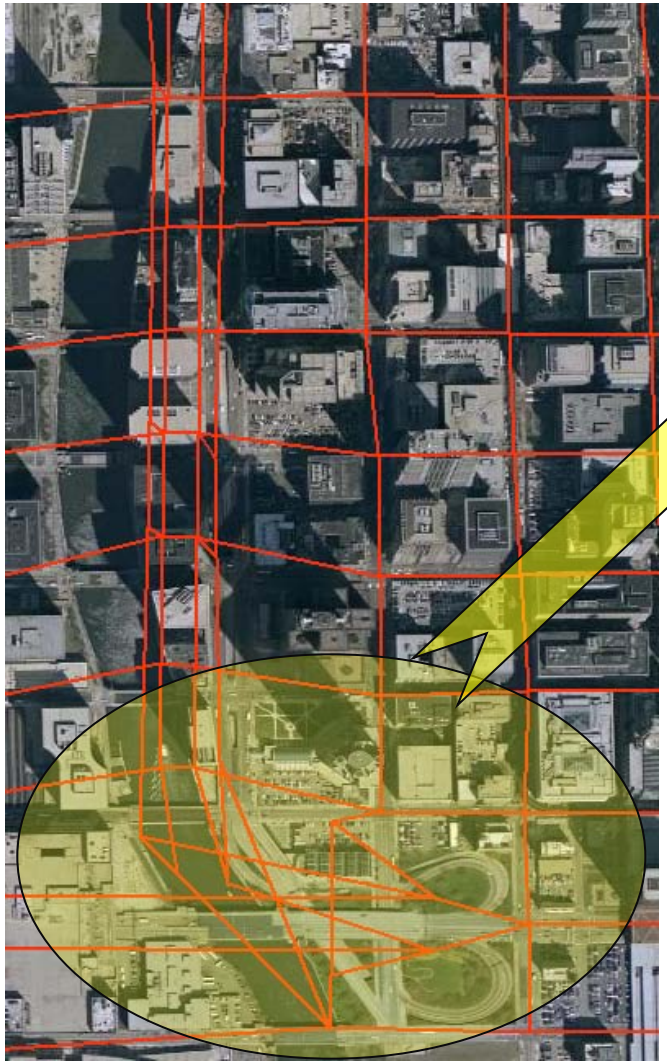
- ~10,000 square miles
- Road network
  - 40,000 links
  - 14,000 intersections
  - 110,000 locations
- ~26.5 million vehicle trips
- ~1.5 million transit trips
- Trip tables
  - Break-down by purpose (work, truck, airport, and many more)

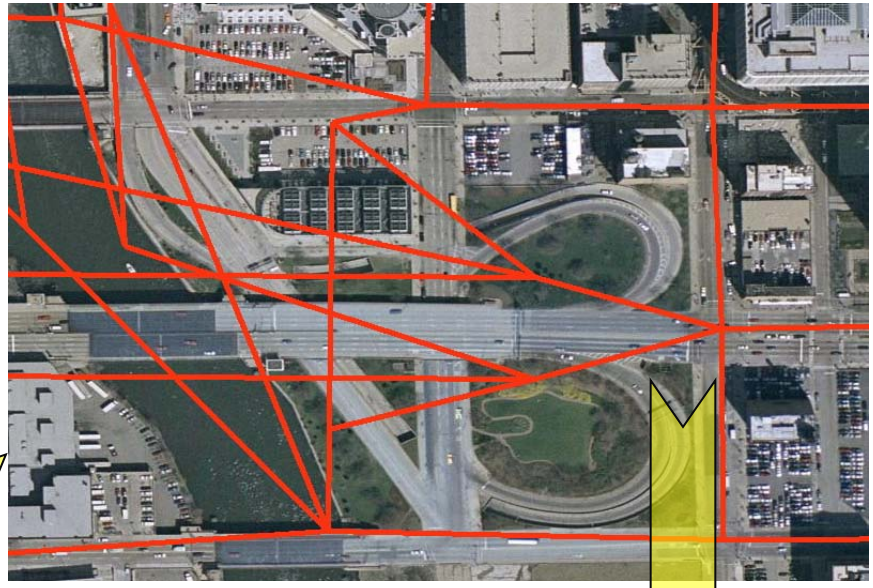


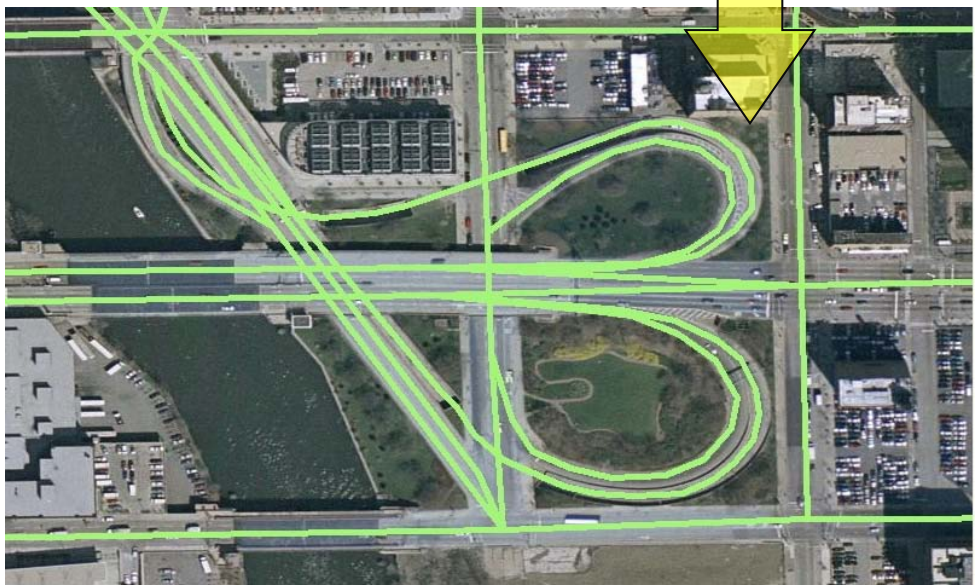
Fundamental Capabilities of the TRANSIMS Approach

- **Multi-modal transportation** (vehicles, buses, trains, walking, bicycles,…)
- Extremely **large simulation areas**, e.g., Chicago (10,000 square miles)
- Fully time-aware routing of **each individual traveler** for all travel modes
- Microsimulation for large metropolitan areas to determine the interactions between travelers and vehicles to determine **second by second movements**
  - Determination of **vehicle interactions**, such as lane changes, speed changes, passenger loading and unloading, …
  - **Interaction with the road network**, (e.g., with traffic signals, speed limits, turn lanes, transit vehicles, …)
- This approach overcomes the limitations of traditional traffic forecasting models:
  - Delivering **transportation system performance** as a full function of time instead of static solution for a few time periods (e.g., am and pm peaks)
  - Microscopic interaction between vehicles and travelers delivers **accurate results** compared to simple volume delay functions and aggregate data.
- Main challenges: **Massive demands on computation time** and a need for extremely detailed input data

Network Editing

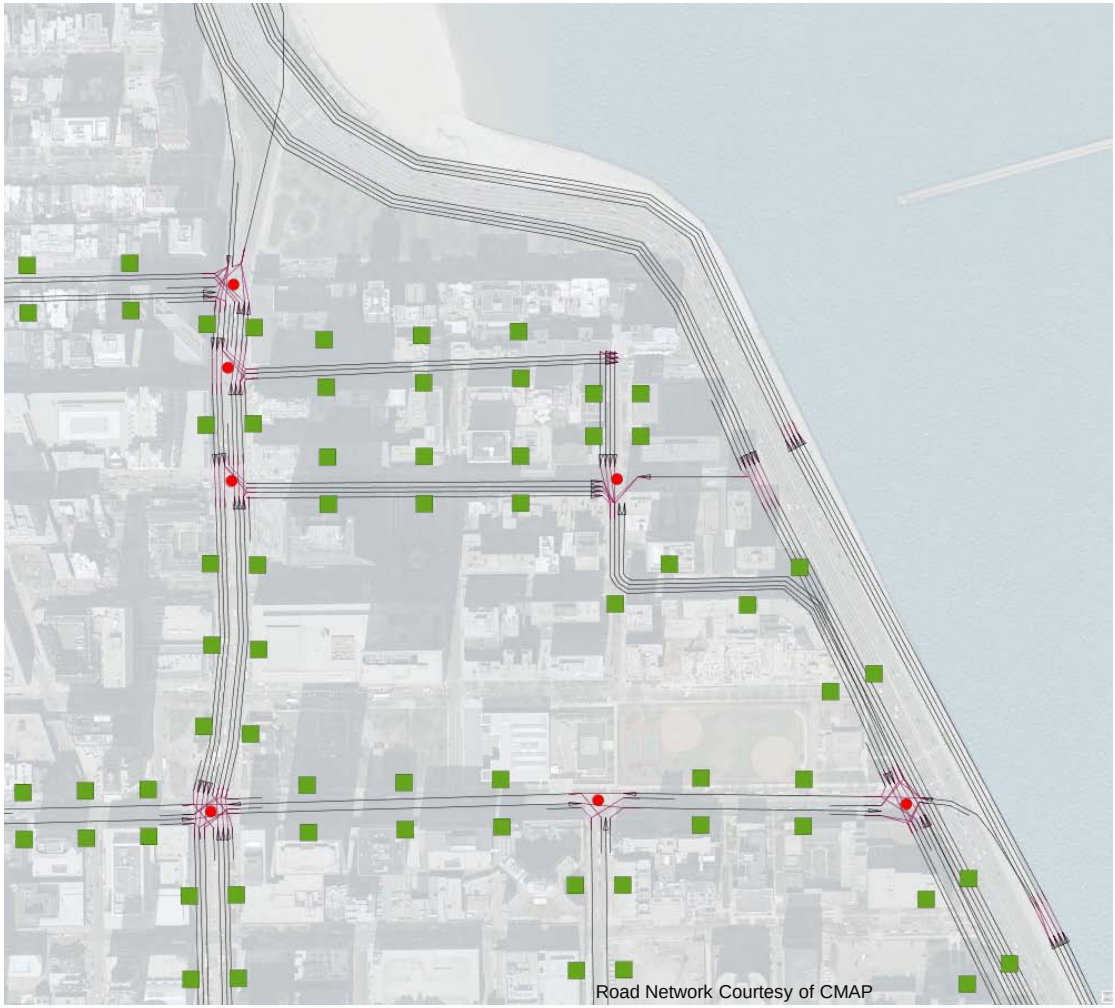






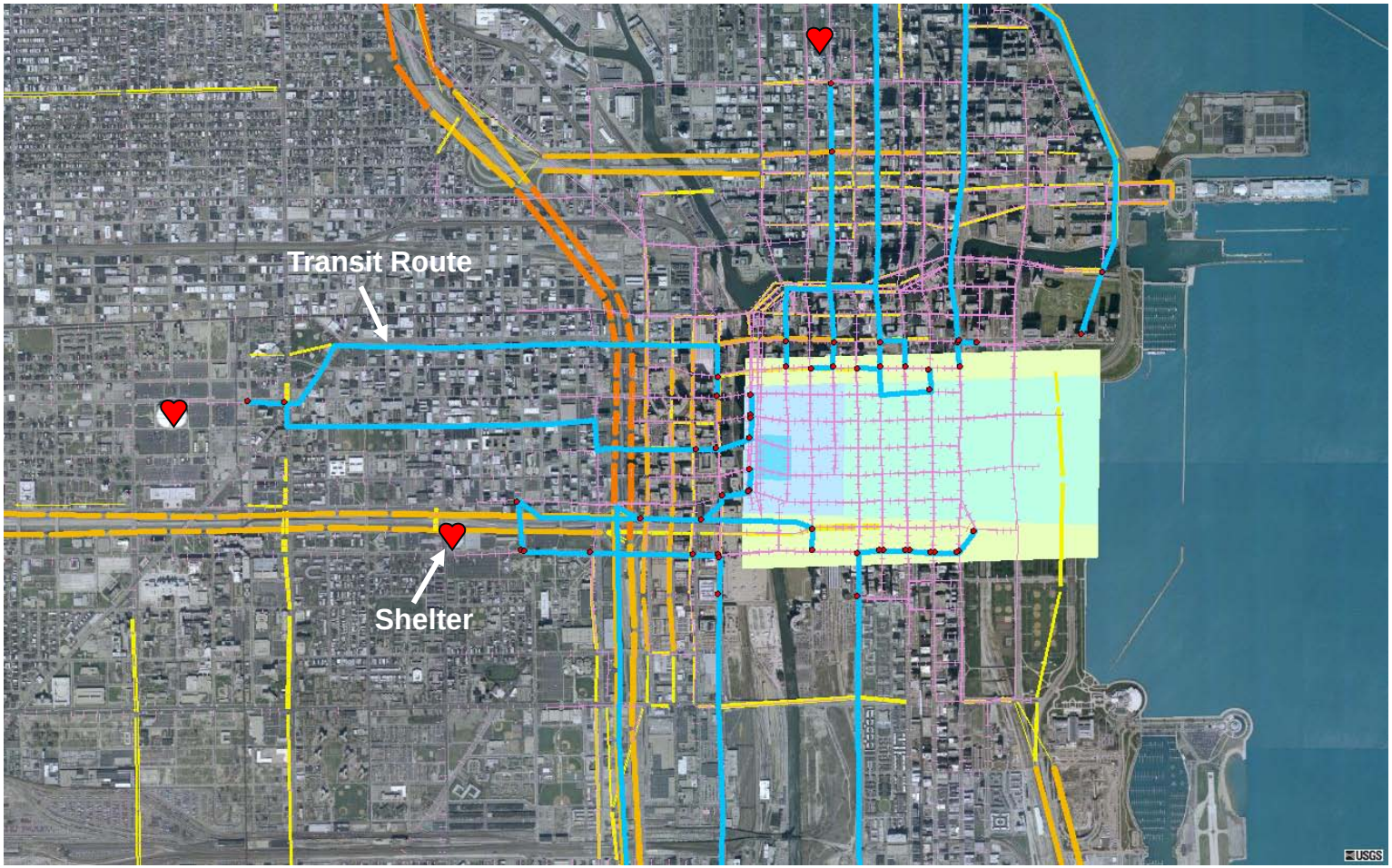
Current Status

- Each individual lane is modeled
- Pocket lanes are modeled
- Lane Connectivity
- Signals
  - Phasing
  - Timing
- Parking
- Many more details



Complex Evacuation Strategies

Scenario 4: Evacuation via Transit to Shelters



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Bridge Hydraulics and Computational Fluid Mechanics

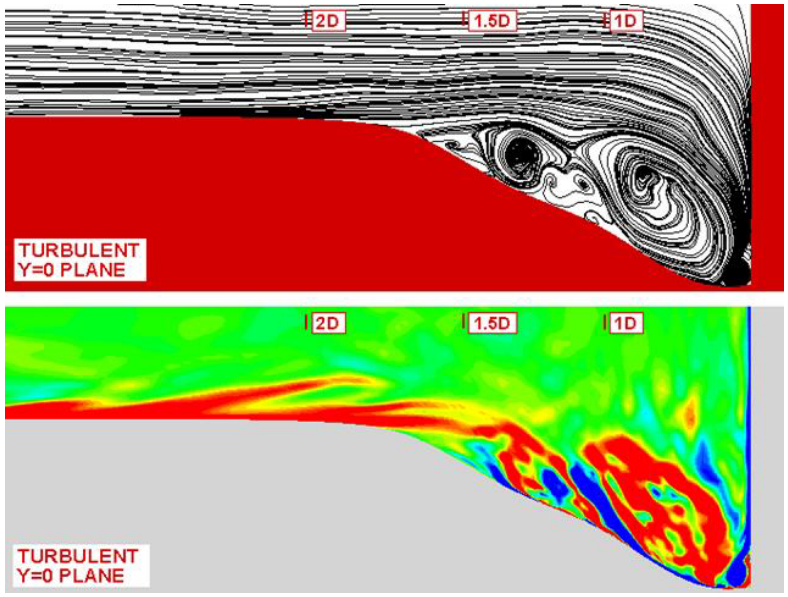
In cooperation with the U.S. Department of Transportation,
Northern Illinois University and the University of Illinois

Areas of CFD Application

- Bridge scour during floods (100 or 500 year flood)
  - Area of active research in model development
  - Turbulent, multiphase, 3D, open channel flow/porous media problem
- Hydrodynamic forces on bridge supports and decks during floods and storm surges
- Fish passage structures
- Aerodynamic forces on bridges and road side hardware (signs, lights, etc.)
- Dispersion of toxic, radiologic, or biologic agents in urban environments

Current CFD Collaborative and User Projects

- Hydraulic Forces on Bridge Structures and Scour in Floods
  - FHWA Turner Fairbank Highway Research Center (TFHRC)
  - University of Nebraska
  - Northern Illinois University
  - Argonne National Laboratory
- Investigation of Bridge Pier and Abutment Scour Using Large Eddy Simulation (LES)
  - University of Iowa



Flow in a scour hole in front of a pier

- Wind Loads on Highway Sign and Traffic Signal Structures
  - University of Iowa
- LES Analysis of Turbulent Flow Over Beds of Packed Spheres (New)
  - University of Illinois Champaign-Urbana
  - Argonne National Laboratory
- Fish Passage through Culverts (New)
  - TFHRC, Argonne National Laboratory, University of Nebraska

Bridge Scour is a Major Problem

- Scour is the erosion of stream or river bed material
  - At bridges scour can cause bridge failure
- About 500,000 bridges in the National Bridge Registry are over waterways
  - Over 85,000 (17%) are considered vulnerable to scour
  - About 26,000 (5%) are classified as scour critical
- Of over 1000 U.S. bridge failures over the last 30 years, about 60% were caused by foundation scour
  - ~20 bridges/year fail due to scour
- Computational analysis can help make optimum use of federal and state DOT resources used for bridge infrastructure
  - Improve identification of high risk bridges
  - Help identify optimum scour countermeasures and bridge modifications/designs

Scour Analysis and Modeling Alternatives

- Current standard: algebraic formulas and correlations from HEC 18
- Single-phase flow with a "moving boundary" formulation based on comparison of the local shear stress at the bottom surface with the "critical shear stress" at which the scour is assumed to initiate.
- Multi-component flow technique with sediment transport as a scalar
  - Flow field is a single continuum
  - Sediment transported as a scalar concentration
    - *Scour rate source at packed bed interface*
    - *Settling rate*
  - Fluid properties are a function of sediment concentration
- Full multiphase flow – water and particles treated as interpenetrating continua
  - Model is the most promising (most fundamental physics)
  - Most computationally intensive
  - Fluent and Star-CD do not have models (terms in PDE's) to account for stationary beds

Real Bridge CFD and CSM Analysis Data Needs

- Bridge geometry and materials
- Topology of river channel and flood plains upstream and downstream of bridge
- Soil material data – at depths of interest
- Channel and flood plain surface conditions
  - Bed roughness, vegetation, rip-rap, etc.
- Flow rates for various flood conditions
- Data can be reduced for single component analysis (a pier)
  - Pier geometry (including footing), materials, and load
  - Soil material data and bed contour around pier
  - Flow rates for analysis

Illustrations of Scour

Abutment Scour

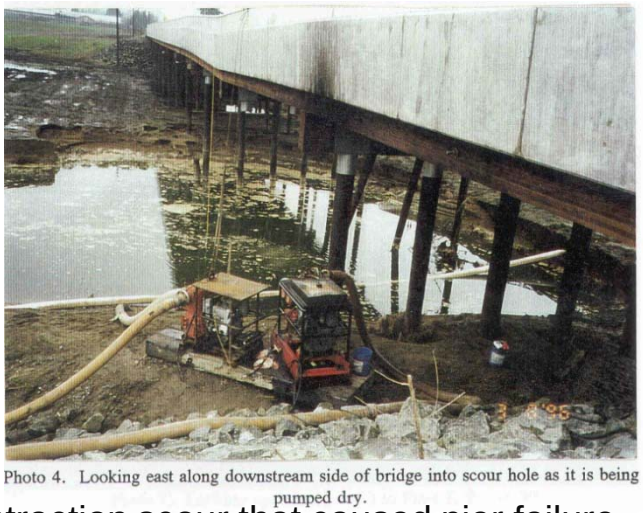


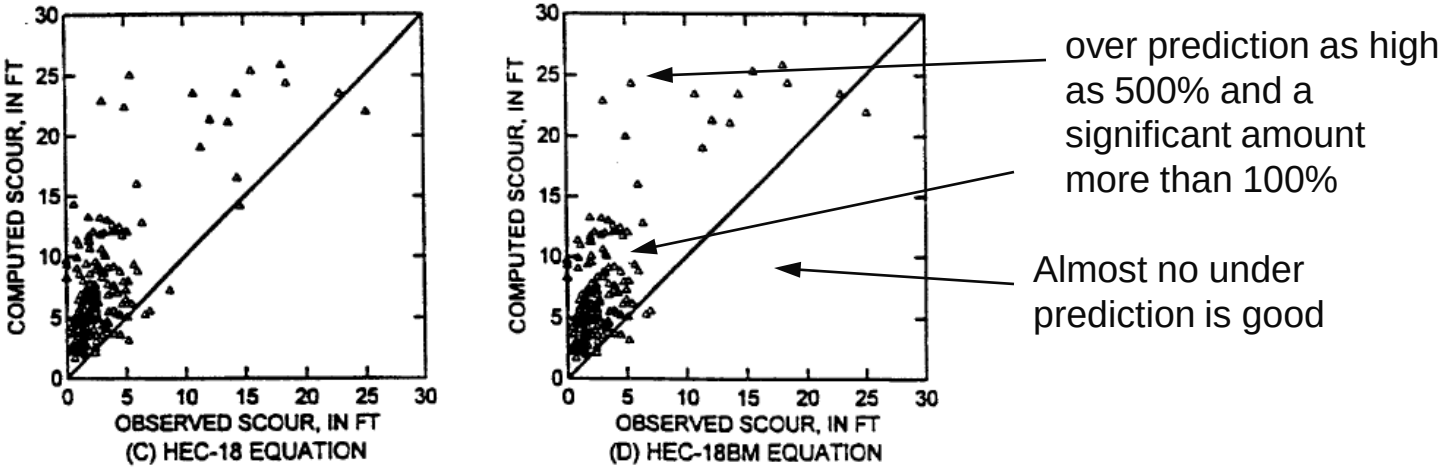
Photo 4. Looking east along downstream side of bridge into scour hole as it is being pumped dry.

Contraction scour that caused pier failure

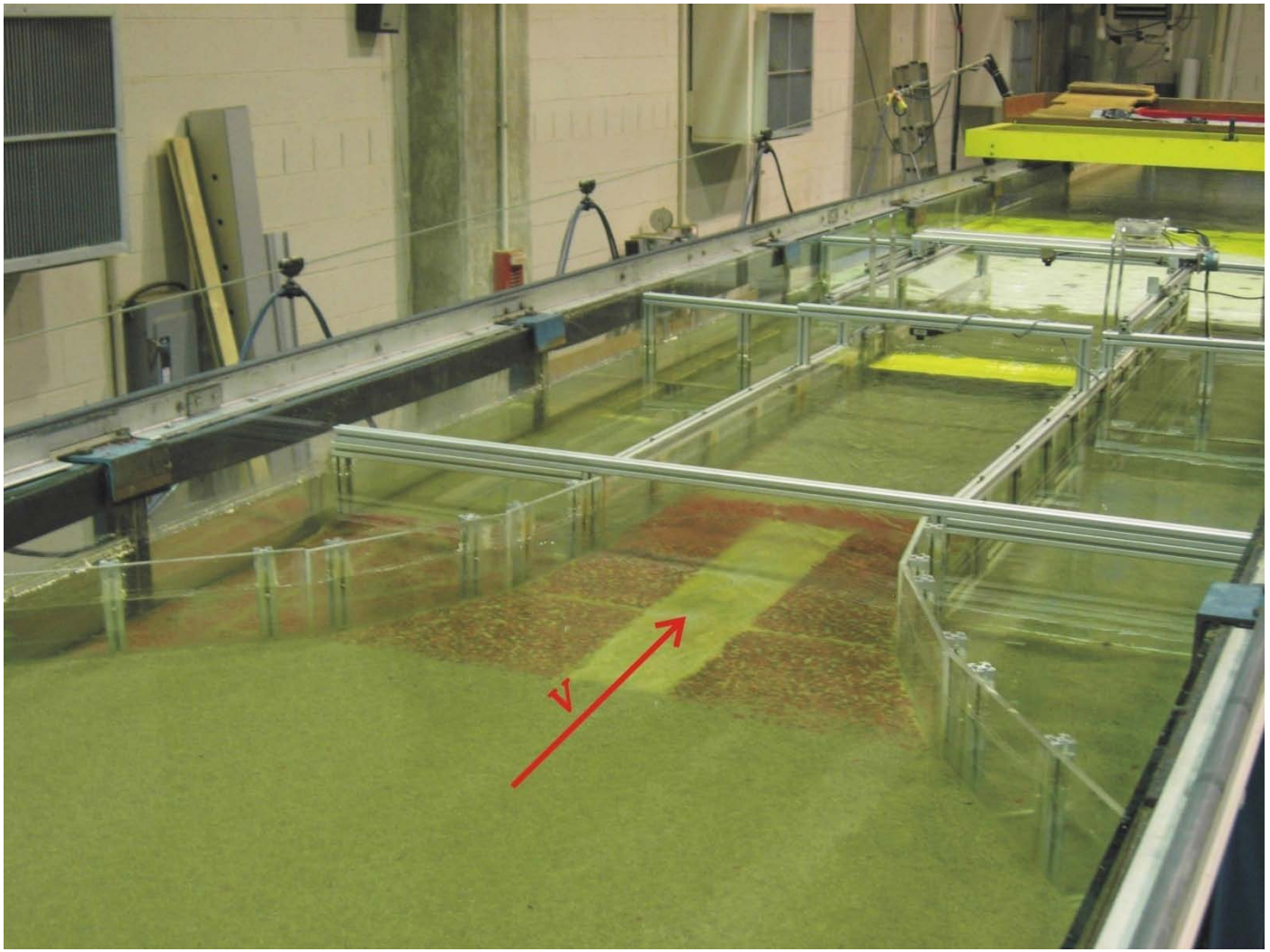
Pier scour extending below piling supports

Difficulties in Bridge Scour Risk Assessment

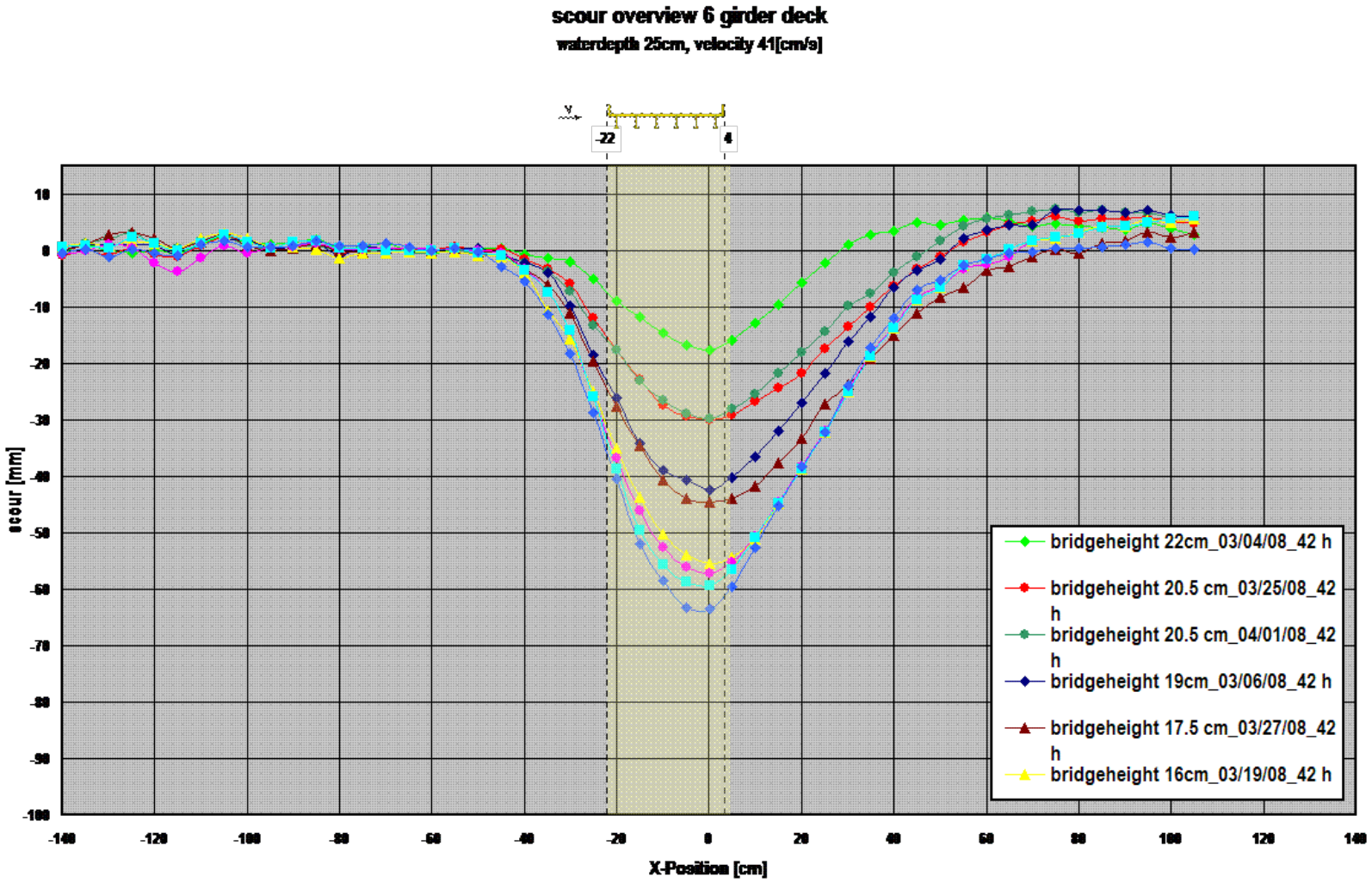
- Federal Highway Administration HEC 18, “Evaluating Scour At Bridges” is the guideline used by state DOTs.
  - Scour formulas are algebraic (do not employ advanced analysis techniques)
  - Formulas are based primarily on scour of non-cohesive bed material (typically sand)
  - Formulas are conservative – as they must be
    - *Better analysis can still have a large engineering safety factor while greatly reducing the cost of bridge maintenance and monitoring*



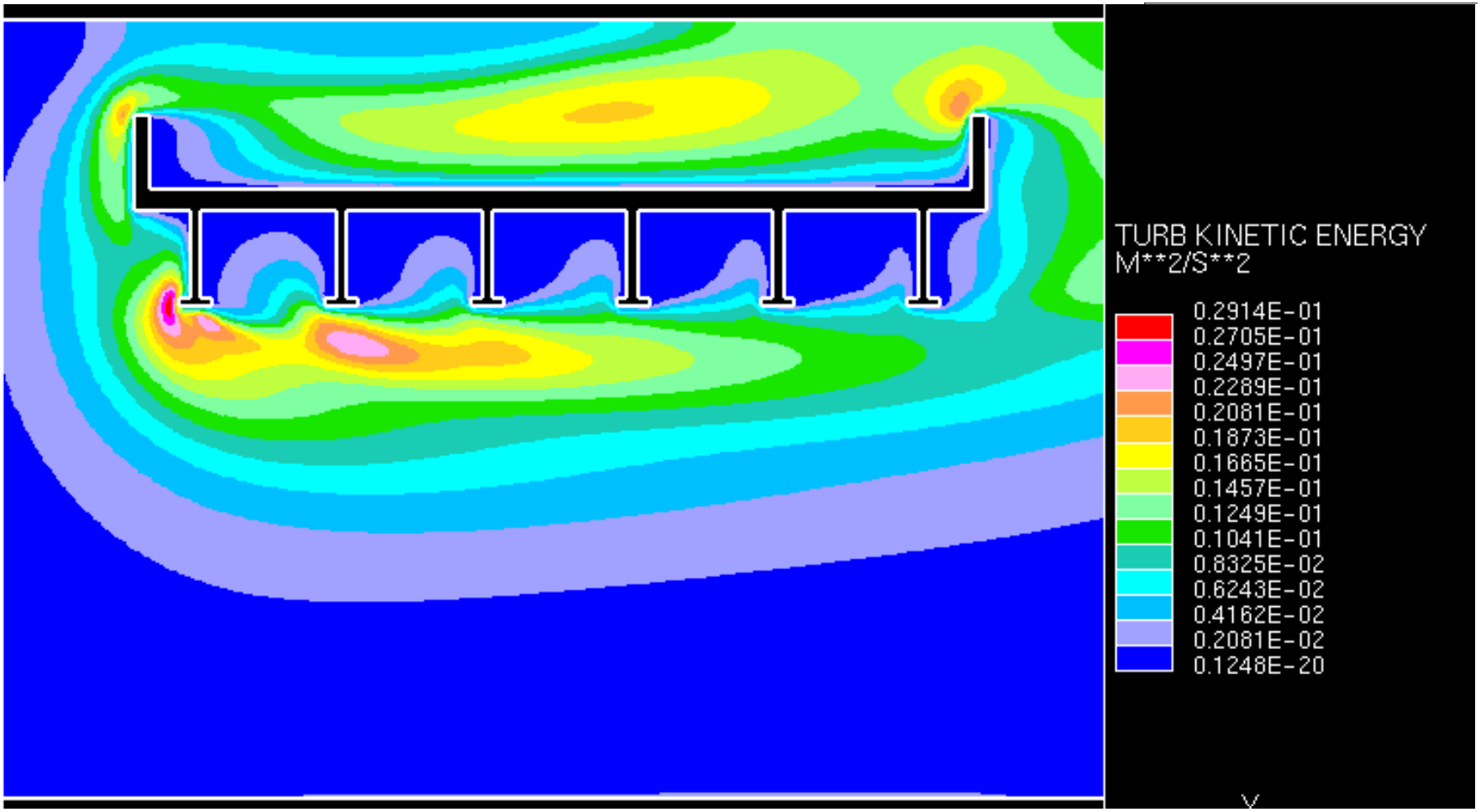
Turner-Fairbank Highway Research Center Pressure Scour Experiments – Scour Flume



Turner-Fairbank Highway Research Center Pressure Scour Experiments – Results for 1 mm Sand



Example: 2D STAR-CD Model for Reduced Scale Inundated Bridge Deck



CFD Software on the TRACC Cluster

- CD-adapco – unlimited license
  - STAR-CD
  - STAR-CCM+
  - STAR-DESIGN
- ANSYS – 4 seat 32 core license
  - FLUENT
  - GAMBIT
- Flow Science – University of Nebraska only evaluation
  - FLOW-3D
- University of Iowa Large Eddy Simulation (LES) codes (3) ported to TRACC
  - TRACC provides technical assistance in porting in-house software

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Computational Structural Mechanics

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CSM Areas of Application

- Transportation Structures
  - Bridge Performance Assessment
  - Structural Health Monitoring
  - Pavements
  - Nondestructive Testing Validation (foundations, piers, etc.)
    - *Size, length, qualitative condition, subsurface material*
- Roadside Hardware Safety Performance
- Occupant Safety Assessment and Crash Biomechanics
- Vehicle Crashworthiness
- Transportation Materials
  - Asphalt, concrete, soil, steel

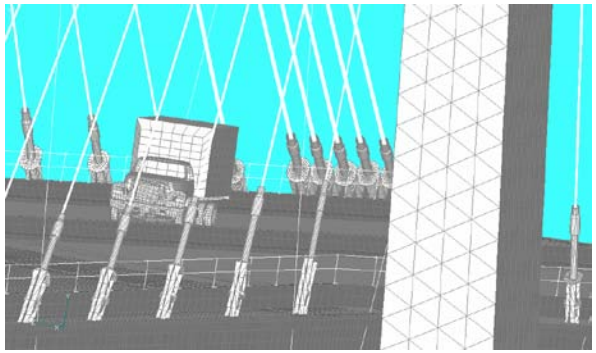
Current CSM Collaborators/Researchers

- Turner Fairbank Highway Research Center (TFHRC)
  - Chaos Theory analysis of cable-stayed bridges
  - Steel Bridge Test Program: Structural integrity assessment of steel bridges, which represent 34 percent of the nearly 600,000 US highway bridges.
- TFHRC Sponsored Project
  - Collaboration between Department of Civil Engineering of Texas A&M University and Delf University of Technology
  - Modeling hot asphalt mix compaction
- National Highway Traffic Safety Administration
  - Biomechanics of traumatic brain injury (TBI) resulting from crashes
- Texas Transportation Institute
  - Analysis and design of roadside safety features
- Louisiana Transportation Research Center
  - Structural performance of flexible pavements

Current CSM Collaborators/Researchers (cont'd)

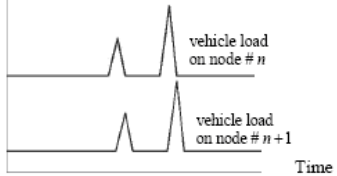
- Michigan Technological University
  - Microstructure-based modeling of asphalt materials
- Northern Illinois University
  - Collaboration between NIU and TRACC
  - Nonlinear analysis of cable-stay bridge cables subjected to traffic and wind loading
- Northwestern University
  - Numerical investigation of single point incremental forming to develop fracture criteria for crashworthiness analysis
- TRACC
  - ANL funded research
  - Modeling stability of bridge piers subjected to riverbed erosion profiles (pier scour)

TFHRC Initial Work: Bill Emerson Memorial Bridge



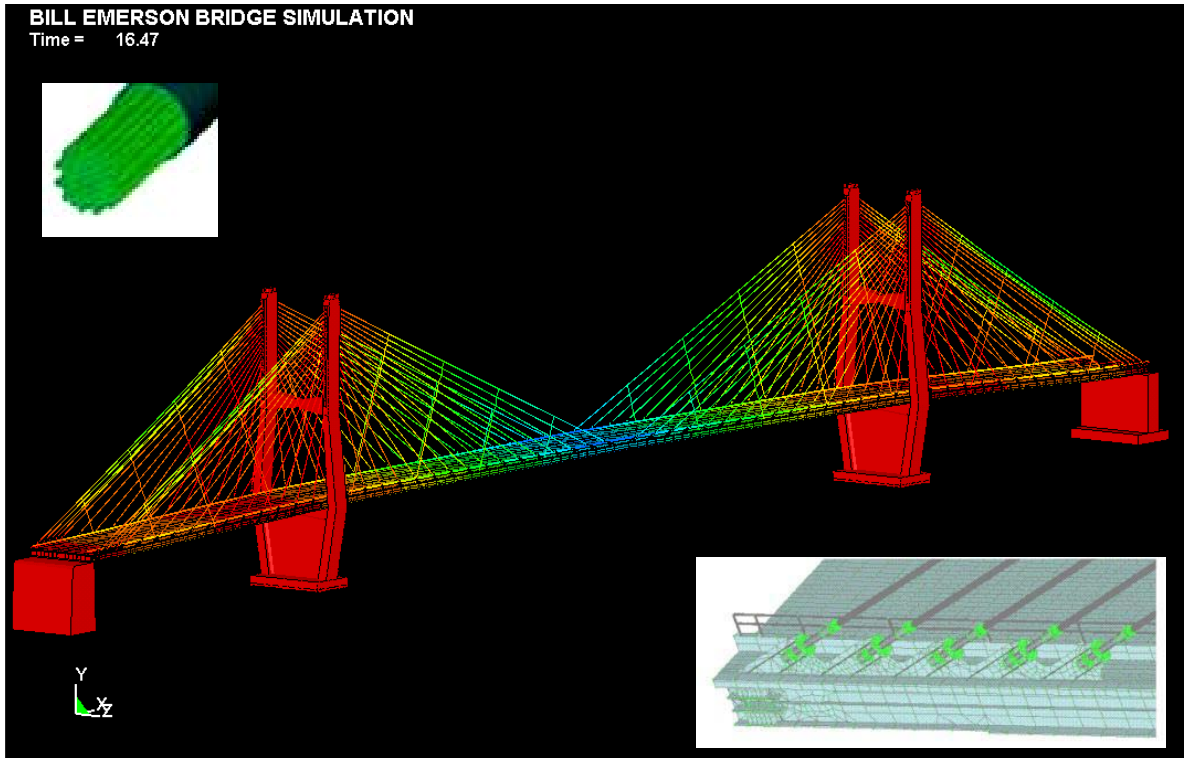
PDP process[7]:

$$\eta(t) = \sum_{k=1}^{N(t)} \sum_{l=1}^{M_k} Y_{kl}\,\delta(t - \tau_{kl})$$



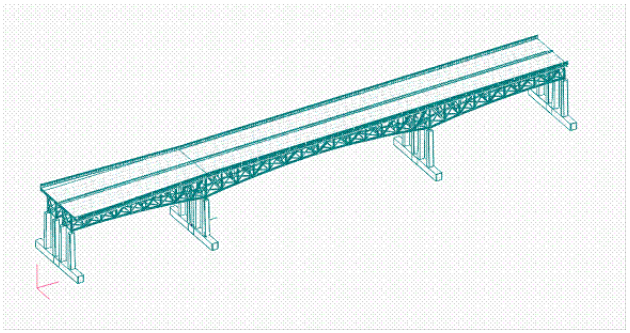
- To accurately determine the structural response of bridges to loadings from traffic, high winds, river currents and earthquakes, it is necessary to develop high fidelity numerical (finite element) models and perform transient dynamic analysis using state-of-the-art cluster computers.
- TFHRC is currently performing simulations on the TRACC cluster of the Bill Emerson Memorial Bridge subject to traffic loading.
- Simulation results are being inputted into TFHRC-developed Chaos theory software to see if chaotic vibrations of the stay cables can occur and also for gathering Structural Health Monitoring data for comparison with field measurements.

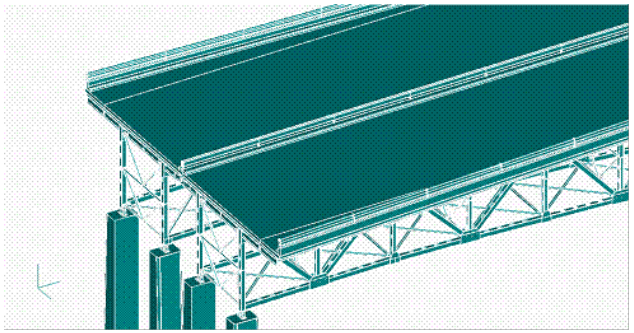
FE Model of Bill Emerson Memorial Bridge



- The figure above shows a 1,000,000-element finite element model that is currently being run by TFHRC staff on the TRACC cluster.
- For a simulation time of 100 sec (i.e., real world time) of traffic loading and using 252 CPUs, the wall-clock time (~computation time) was 10 days.
- Defining Characteristic: Large FE model & very long compute time.

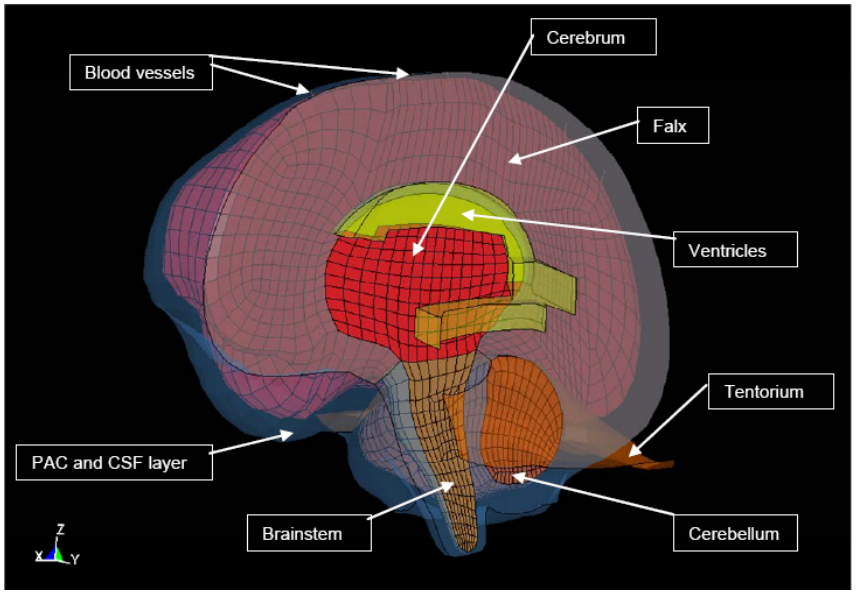
TFHRC Current Work: Patroon Island Bridge (NY)

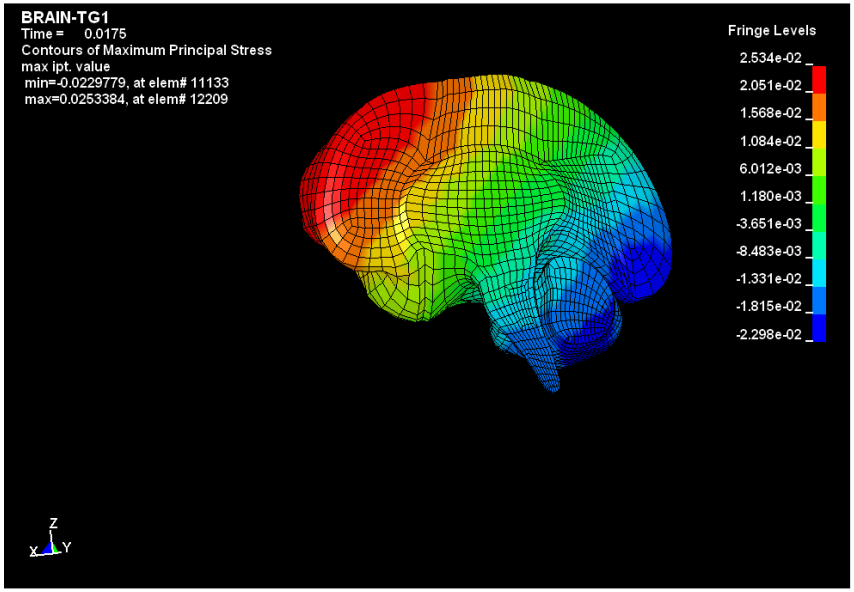




- Last year, the collapse of the I-35 bridge in Minnesota greatly alarmed the DOT.
- A modeling and simulation effort was recently started by TFHRC to analyze other bridges of similar design, such as the Patroon Island Bridge, which is a major crossing of the Hudson River in Albany NY.

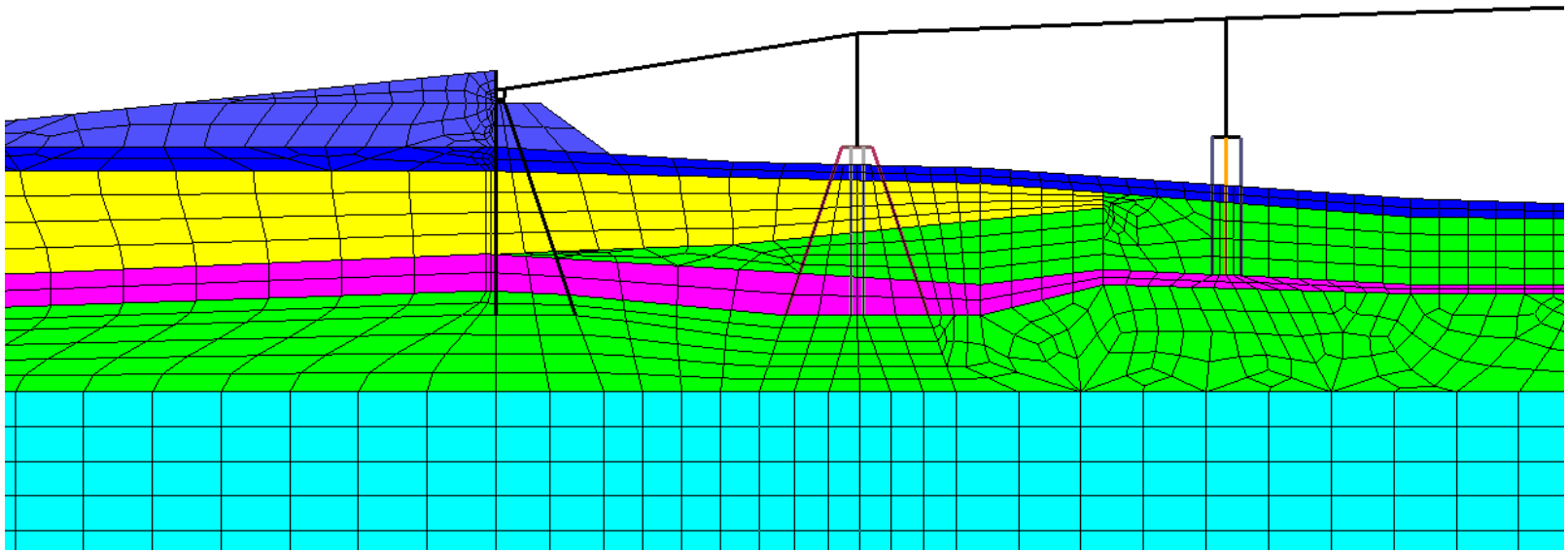
NHTSA Current Work: Traumatic Brain Injury





- Motor vehicle crashes remain one of the major causes of TBI in the US only second to falls.
- Finite element models have proven to be viable tools to better understand the biomechanics of TBI.
- Probabilistic analyses are being performed to identify important random variables and their effect on response distributions.
- Defining Characteristic: Small FE model, short compute time but hundreds of runs.

Structural Stability = Super-structure + Substructure + Foundation Soil



- To maintain a stable bridge structure, the superstructure, the substructure and the foundation soil must retain their load carrying capacities.
- Bridge pier scour can drastically reduce the load carrying capacity of the foundation soil by displacing the soil around the piers/piles.
- This may lead to failure of the substructure and the superstructure.

Computational Mechanics Software at TRACC

- LS-DYNA
  - License for 288 cores (CPUs)
  - Multi-Physics software (FE, SPH, MMALE)
- ABAQUS
  - 21 Token License (34 cores max for 1 user)
  - General-purpose nonlinear finite element software
- TrueGrid
  - License for 1 core
  - Quadrilateral/Hexahedral mesh generator
  - Applicable to both CSM and CFD codes
- User Developed Software

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Computing, Networking, and Collaboratory Facilities

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Using TRACC Resources and Facilities

Argonne established the Transportation Research and Analysis Computing Center (TRACC) for the U.S. Department of Transportation (USDOT). TRACC provides high-performance computing resources based on advanced, massively parallel computing systems, primarily to the transportation research and development (R&D) community. Access to the TRACC cluster is provided to users based on requests/proposals for allocations of computing resources to TRACC.

Requests for TRACC computing resources are granted to the following individuals and groups:

- *Researchers associated with U.S. Universities*
- *Universities and private organizations under contract to USDOT*
- *Organizations funded by state and city departments of transportation*
- *USDOT R&D programs*
- *Other Federal Agencies*

TRACC also considers resource allocations to other non-USDOT transportation-related R&D programs or projects on a case-by-case basis.

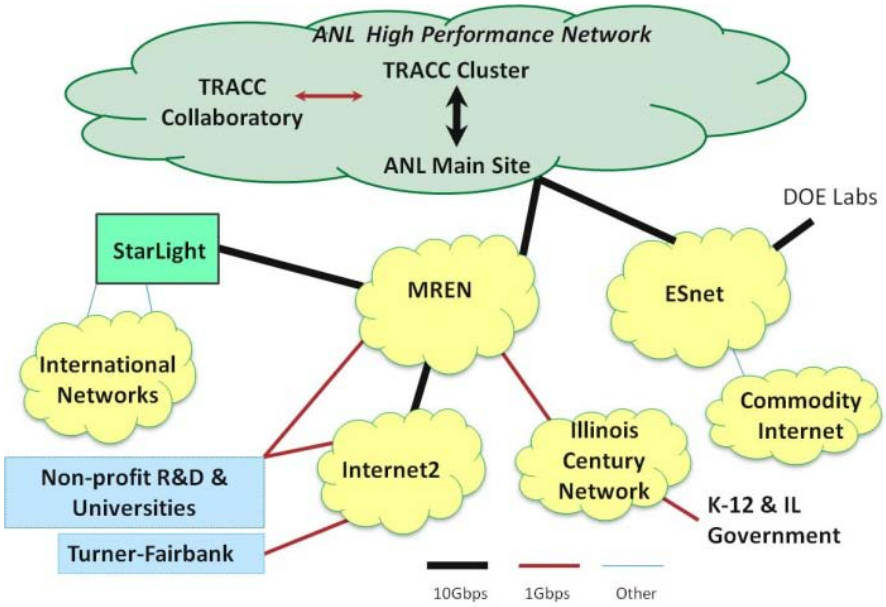
Visit http://www.tracc.anl.gov "Becoming a User" for more information

TRACC Cluster Computer

- 128 compute nodes/512 cores
- 180TB of RAID storage
- Gigabit Ethernet network
- Low Latency InfiniBand network
- 160TB tape backup system

TRACC Network Connectivity

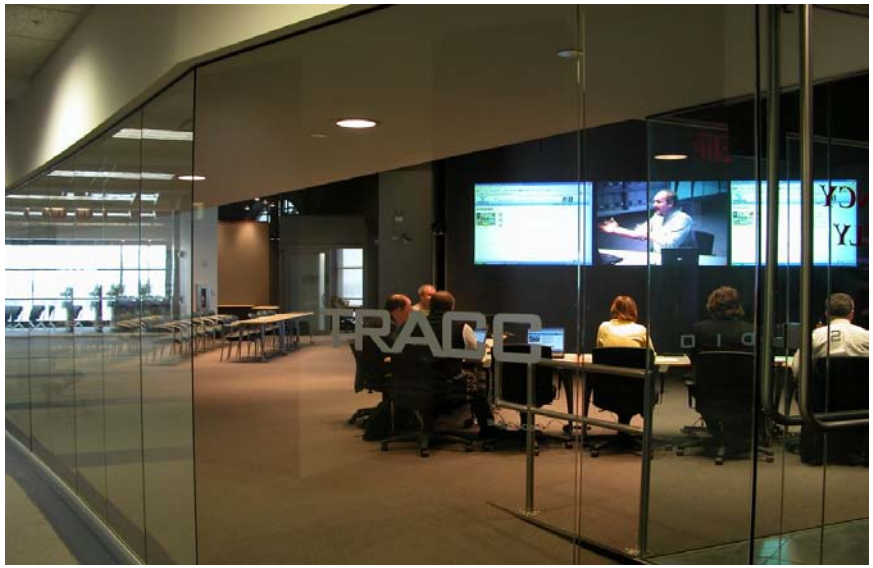
- TRACC is a part of the Argonne high performance computer network
  - The Flight Center is connected via a 1Gbps link to the DuPage National Technology Park Communications Center where the TRACC cluster is located
  - The ComCenter is connected to the main Argonne site via a 10Gbps link

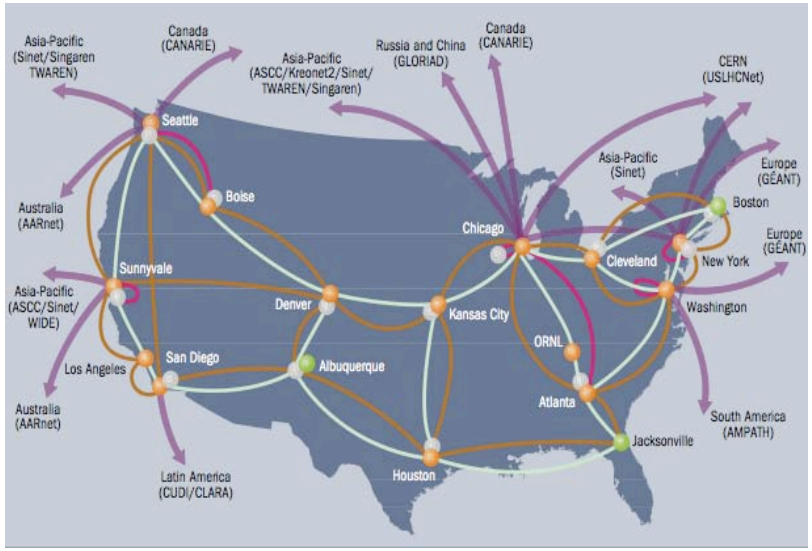


- TRACC, via the Argonne network, has network access to university, federal, state and local, and commercial transportation research centers world-wide via:
  - The Department of Energy network (Esnet)
  - The Metropolitan Research and Education Network (MREN)
  - The research and education network, Internet2
  - StarLight an international network connection point

TRACC Collaboratory

- Outreach
- Training
- Collaboration
- Visualization
- Technology Enablement





TRACC Collaboratory – User Benefits

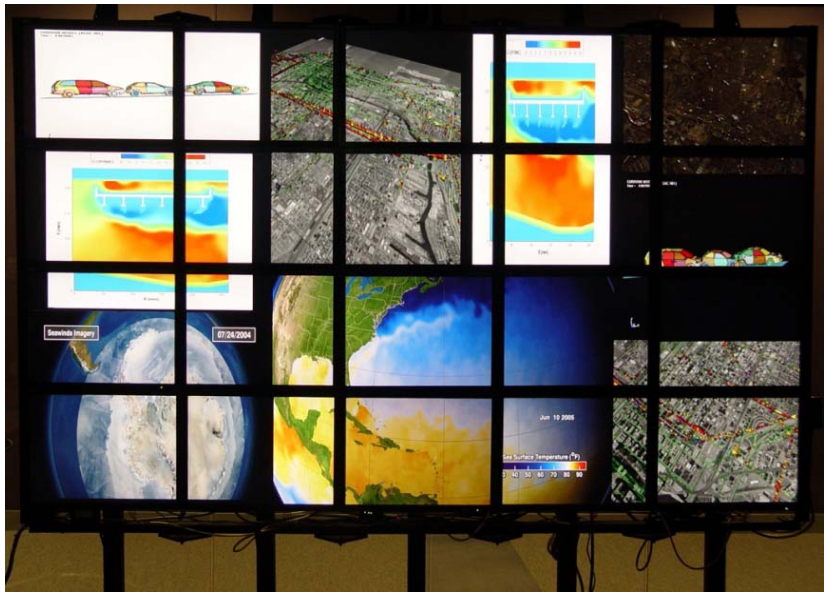
- State-of-the-art outreach and training facility
- Ability to share video/audio and data among geographically dispersed participants
- Collaboration facility for distributed teams, using advanced visualization and communication technologies
- Distribution of simulation and modeling results – in real-time to distributed transportation research centers

TRACC Collaboratory - Capabilities

- Collaborative conferences, meetings and training with geographically distributed participants
- Demonstration and Training Theatres
  - Two 15’ x 18’ rear-projection walls
  - Video production and streaming system
  - Multiple cameras (including High Definition)

TRACC Collaboratory - Capabilities

- High-end Visualization Equipment
  - Passive stereo virtual reality display
  - High performance graphics cluster (20 panel LCD tile display; 8000 x 4800 pixel resolution)
  - HD Stereo Theater projection system (1920 x 1080 pixel resolution)

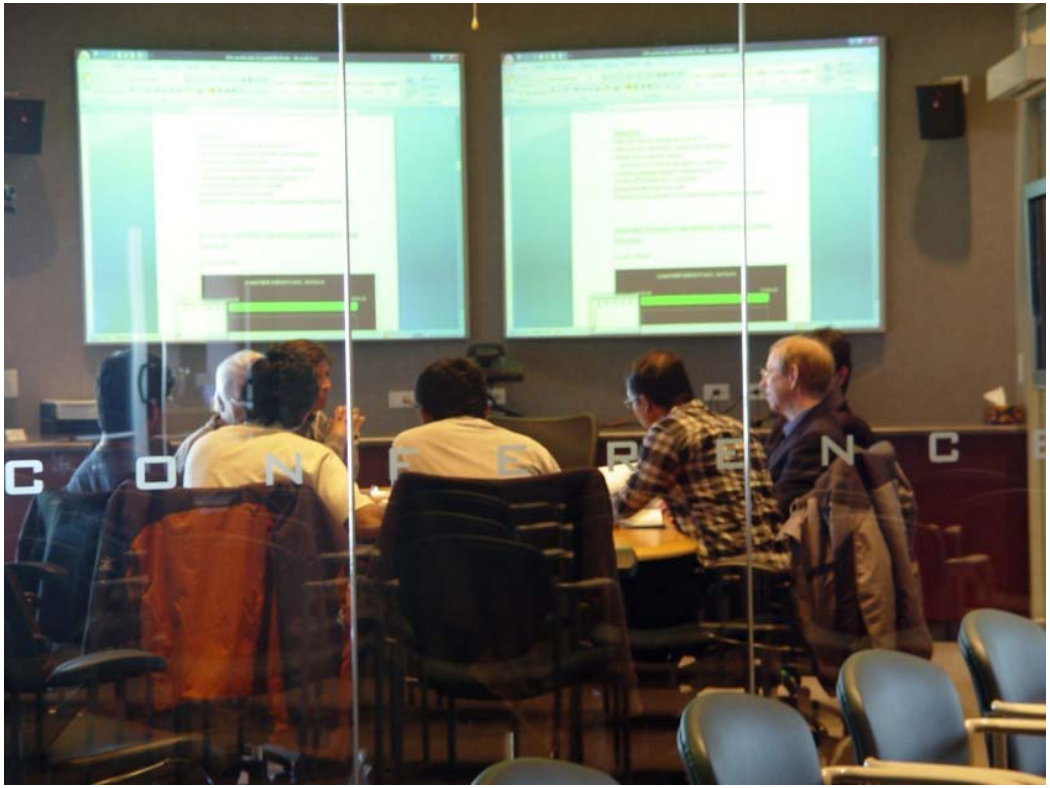


TRACC Collaboratory - Capabilities

- Multi-site Video-Conferencing Technologies
  - Web Conferencing (Adobe Acrobat Connect)
  - Multiple Video-teleconferencing Systems (H.323), including High Definition (HDX 8004 and HDX9004)
  - Multiple Access Grid Nodes (also portable AG node equipment)
- Wireless networking throughout facility
- Broadband access to global research and education networks

Video Conference Technologies

- Adobe Acrobat Connect
  - Accessible via Mac/Windows with low bandwidth, standard browsers
  - One-to-many model
  - Interactive chat
  - Data sharing
  - Transmission of Presentation audio and video
  - Archive capability



Video Conference Technologies

- H.323 technology
  - Multi-site interaction with data sharing (H.239)
  - Multiple participants at each site
  - Higher quality, higher bandwidth requirement
  - Live video streaming and archiving capability
  - Interconnectivity w/ Adobe Acrobat Connect

Video Conference Technologies

- AccessGrid
  - Multi-site interaction with data sharing
  - Multiple participants with multiple streams at each site
  - Highest quality, highest bandwidth requirement
  - Live video streaming and archiving capability
  - Interconnectivity with H.323

TRACC Contact Information

- Director's Office — Dave Weber, Director; Mike Boxberger
- Systems Administration — Jon Bernard
- Traffic Simulation — Hubert Ley; Young Soo Park; Michael Hope; Vadim Solokov
- Computational Structural Mechanics — Ronald Kulak
- Computational Fluid Dynamics — Steven Lottes; Tanju Sofu
- Collaboratory for Advanced Visualization and Communications — Larry Amiot; Tom Brown; Joe Reitzer; Jonas Talandis; Gail Tate

www.tracc.anl.gov tracc-help@anl.gov (630) 578-4250